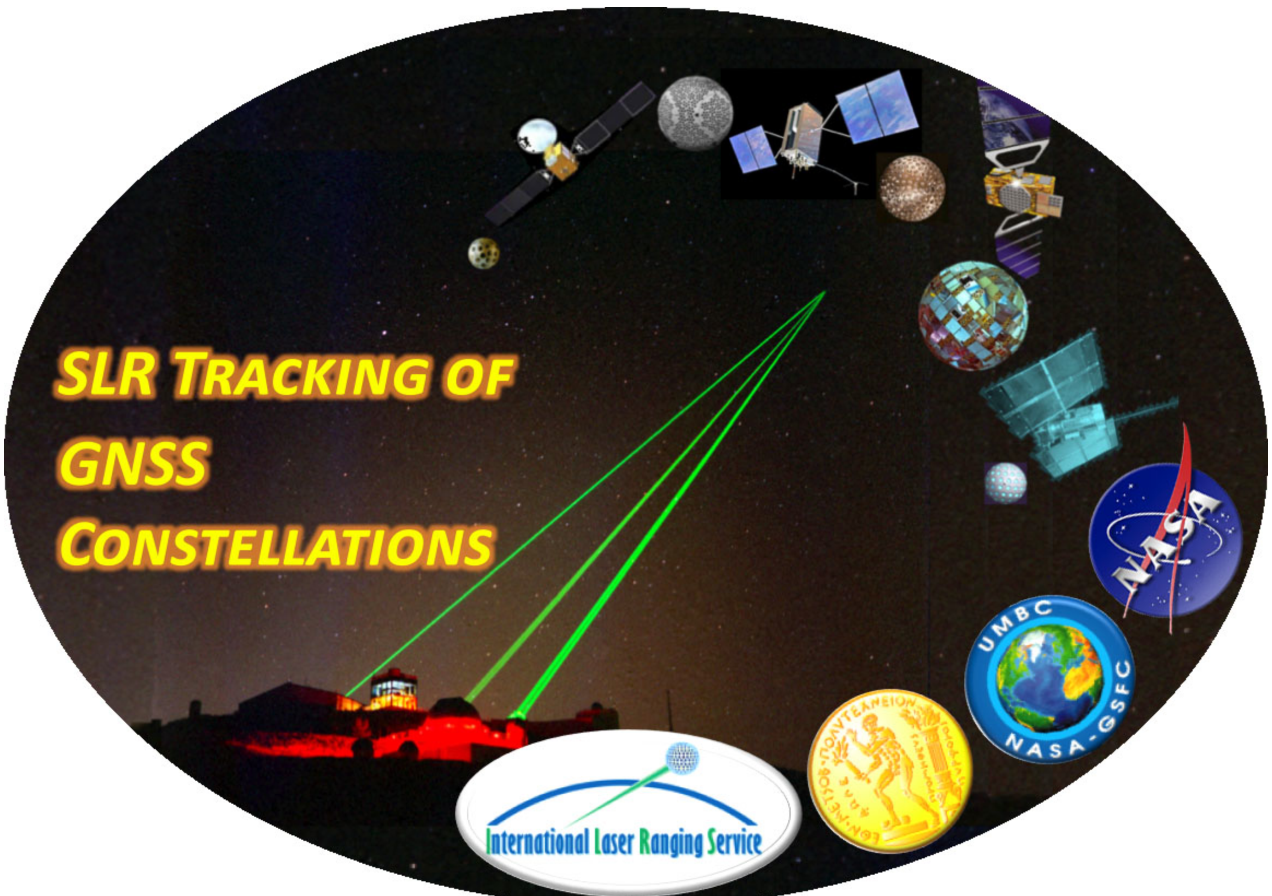
Joint GGOS/ILRS Study Group
LAser Ranging to GNSS s/c Experiment
Expanded SLR Tracking of GNSS Satellites
(LARGE)

Technical University of Vienna
April 28, 2014
18-00 – 20:00

BACKGROUND

First Meeting to Coordinate SLR Tracking of GNSS Constellations

2009 METSOVO ILRS WORKSHOP



PROCEEDINGS OF THE 2009 ILRS METSOVO WORKSHOP

Proceedings of the Workshop can be accessed from:

http://www.ntua.gr/MIRC/ILRS_W2009/mainpage.html

and from CDDIS (currently inaccessible 25/4/2014):

http://cddis.gsfc.nasa.gov/metsovo/index.html

A lot of the Constellation-specific information that was collected at that time needs to be updated now with material that became available since 2009.

ILRS Workshop Summary Series

International Laser Ranging Service

International Technical Laser Workshop on SLR Tracking of GNSS Constellations

50 Years of Satellite Geodesy and Geodynamics
On the Occasion of Prof. George Veis 80th Birthday

Presentation of Position Papers
Session Summaries
&
The Position Papers

Edited by
Erricos C. Pavlis
Goddard Earth Sciences and Technology Center
University of Maryland, Baltimore County

International Laser Ranging Service - 2009

Joint GGOS/ILRS Study Group
LARGE: LAser Ranging to GNSS s/c Experiment
Expanded SLR Tracking of GNSS Satellites

Motivation:

- At the 18th International Workshop on Laser Ranging it was agreed to expand the GNSS data collection of the ILRS network following the acceptance of a resolution submitted by ROSCOSMOS (see next slide);

Objectives of this Study Group (SG) are:

- Define an operational GNSS tracking strategy for the ILRS that addresses all the requirements from all interested parties;
- Test its realization with a tracking campaign Pilot Project;
- Clarify outstanding ILRS and IGS issues with the GNSS satellites and ground stations.

ILRS Workshop Resolution
18th International Workshop on Laser Ranging
November 11- 16, 2013

- Recognizing:
  - The increasing importance of SLR to the improvement of GNSS performance;
  - The necessity of the SLR technique to the improvement of time, frequency, and ephemeris data products from GNSS;
  - The significant contribution of GGOS to the development of GNSS measurement accuracy through co-location with SLR and other measurement techniques; and
  - The enhancement in station performance that we expect from the next generation SLR systems
  - The availability of full satellite characteristics
- The Participants of the 18th International Workshop on Laser Ranging recommend that:
  - With the example of the fully loaded GLONASS system; the ILRS develop a GNSS tracking strategy and on the basis of it, implement a mission (program) to track GNSS satellites with retroreflectors;
  - Multi-constellation GNSS receivers (GLONASS, GPS, Compass/BeiDou, etc) be co-located at all ILRS stations to improve measurement performance of GNSS and to support GGOS development;
  - All SLR stations should be members of ILRS and participate in the GGOS project.

Members of the LARGE Study Group

- Erricos Pavlis, UMBC/NASA GSFC (Chair)
- Graham Appleby, NERC Space Geodesy Facility
- Rolf Dach, AIUB
- Vladimir Glotov, GLONASS-IAC-PNT (GLONASS)
- Urs Hugentobler, Technische Universitaet Muenchen (IGS)
- Georg Kirchner, Space Research Institute, Austrian Academy of Science
- Cinzia Luceri, e-GEOS S.p.A/ASI
- Steve Malys, NGA (GPS)
- Vladimir Mitrikas, GLONASS-IAC-PNT (GLONASS)
- Horst Mueller, DGFI
- Carey Noll, NASA GSFC (ILRS)
- Michael Pearlman, CfA/NASA GSFC (ILRS)
- Tim Springer, ESA (Galileo)
- Daniela Thaller, BKG (IERS)
- Linda Thomas, NRL (GPS)
- ROSCOSMOS Representative (1)
- China Representatives (2) (Beidou)

Study Group Tasks

- Task #1: Collect the quantitative requirements with supporting documentation from each interested group (Study Group)
- Task #2: Perform any simulations necessary to justify the separate requirements (Study Group)

I

- Task #3: Recommend a unified tracking strategy for the network (Study Group)

II

- Task #4: Implement the strategy with 8 – 10 test stations and assess results (ILRS Central Bureau/SG)
- Task #5: Adjust the strategy as necessary (Study Group)

III

- Task #6: Clarify outstanding SLR issues with GNSS satellites and ground stations (ILRS CB)
- Task #7: Clarify outstanding microwave issues with GNSS satellites and ground stations (IGS CB)

IV

INVENTORY

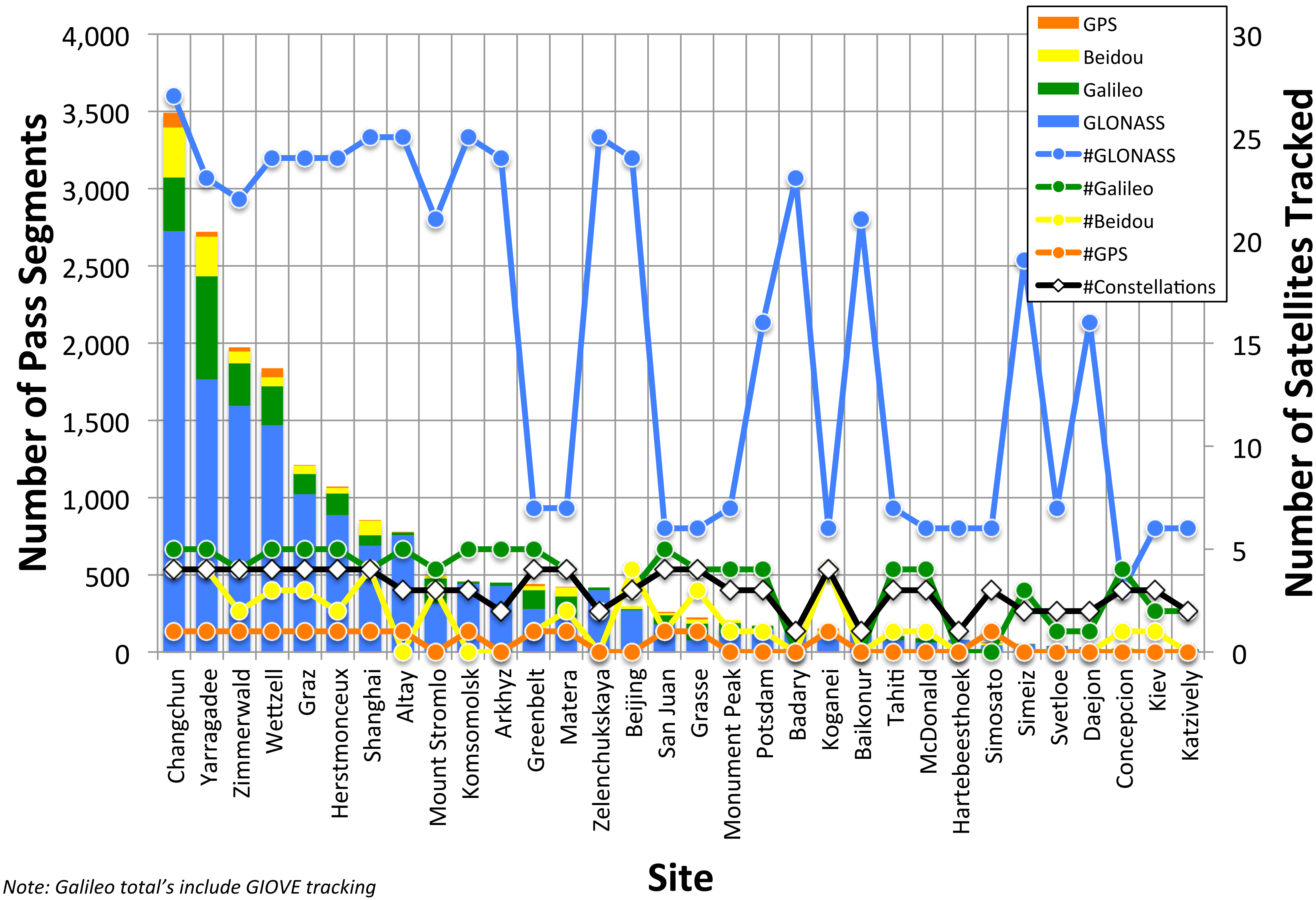
GNSS Constellations: Present Status and Future Outlook

Constellation	Current ILRS Roster	Available	Projected 2018 +
GLONASS	6	24	24
Galileo & GIOVE	5	5	24
Compass/BeiDou	3	3	24
GPS/GPS-III	1	1	24
Total	15	33	96

ILRS GNSS Tracking Summary for November 2013-April 2014

Station	Number of Pass Segments	Constellations Tracked	Number of Satellites
Altay	755	GLONASS, Galileo +GIOVE, GPS	31
Changchun	2,724	All	37
Graz	1,022	All	33
Herstmonceux	887	All	32
Shanghai	689	GLONASS, Galileo, Beidou, GPS	34
Wettzell	1,466	All	33
Yarragadee	1,766	All	33
Zimmerwald	1,596	GLONASS, Galileo, Beidou, GPS	29

GNSS Satellite SLR Normal Point Pass Summary 2013-11-01 through 2014-04-28



Note: Galileo total's include GIOVE tracking

Some Critical Operational Issues

- With the number of SLR targets increasing by hundreds from the GNSS family, it will be critical that SLR systems operate using a very efficient scheme that was adopted since about a year ago:
  - As systems upgrade their equipment with next generation hardware, the increase of the repetition rate from a few Hz to 100s or 1000s of Hz it makes it possible to collect the minimum number of single shots to form a NP with ~ 1 mm precision within a fraction of the allotted time based on satellite dynamics (e.g. 15-30 s for LEO, 2 min for LAGEOS, 5 min for GNSS, etc.)
  - This allows the stations to interleave their targets rather than stay on the same one waiting for the next NP interval, increasing their data yield potentially by several factors
- Based on a review of the data collect over the past year, it seems that very few systems are now taking advantage of this rule, even though we already have a good number of systems operating at the 100 Hz to 2 kHz range.

% of Passes with the New Tracking Rule

100 %

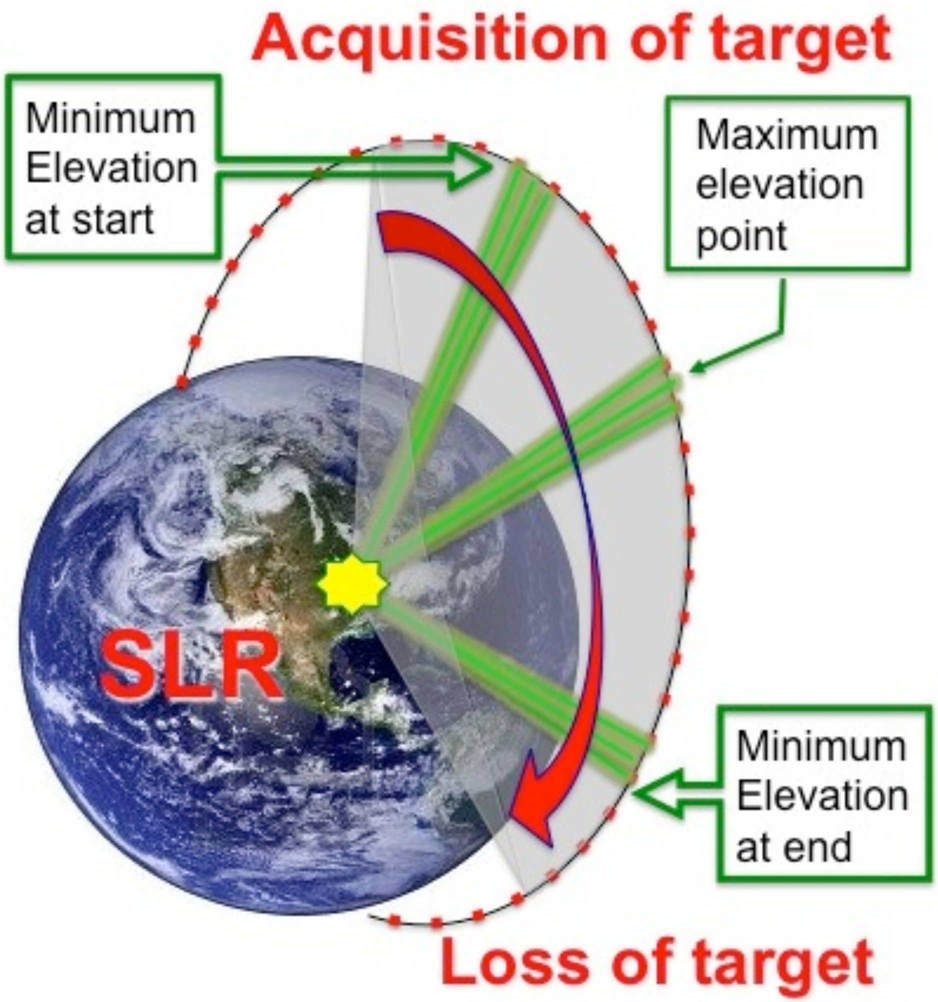
Percent of NP's with FR>=1000	All Satellites	Lageos1	Lageos2	Lares	GNSS
90%+	GRZL (97%)	GRZL (95%) CHAL (95%)	GRZL (100%)	KOML (100%) GRZL (96%)	
80%-89%			CHAL (87%) SHA2 (81%)	SHA2 (85%)	GRZL (82%)
70%-79%	SHA2 (72%)	SHA2 (70%)		CHAL (78%)	
60%-69%	CHAL (69%) POT3 (65%)	ZIML (69%) POT3 (60%)		POT3 (63%)	
50%-59%		KOML (50%)	ZIML (58%) BEIL (50%)		
40%-49%			POT3 (42%)	BEIL (43%)	
30%-39%	BEIL (38%)	BEIL (38%)			CHAL (31%)
20%-29%	KOML (21%)	BAIL (10%)	KOML (29%)	BAIL (25%)	SHA2 (21%)
10%-19%	ZELL (15%) ZIML (14%) BADL (12%)	ZELL (11%)		ARKL (14%) ALTL (11%)	

0 %

Current ILRS Tracking Scenario

Current ILRS policy: GNSS passes include three sectors, taken early, middle and late in the pass, each with three normal points. Normal points (NP) are data spans covering five minutes or 1000 full-rate (FR) points if acquired in less than five minutes.

Current Test: Several stations have already demonstrated capacity to track all of the available GNSS satellites.



REQUIREMENTS (SO FAR)

GLONASS Requirements

as stated during the 18th ILW

- ROSCOSMOS Request:
  - Each participating station should make its best effort to provide two passes per day on each satellite in the GLONASS constellation,
  - one pass in day-time and one pass in night-time,
  - with each pass having 2 NP (1000 FR or 5 minutes), spaced widely apart in the orbit.

BeiDou Requirements & News

Zhang Zhongping

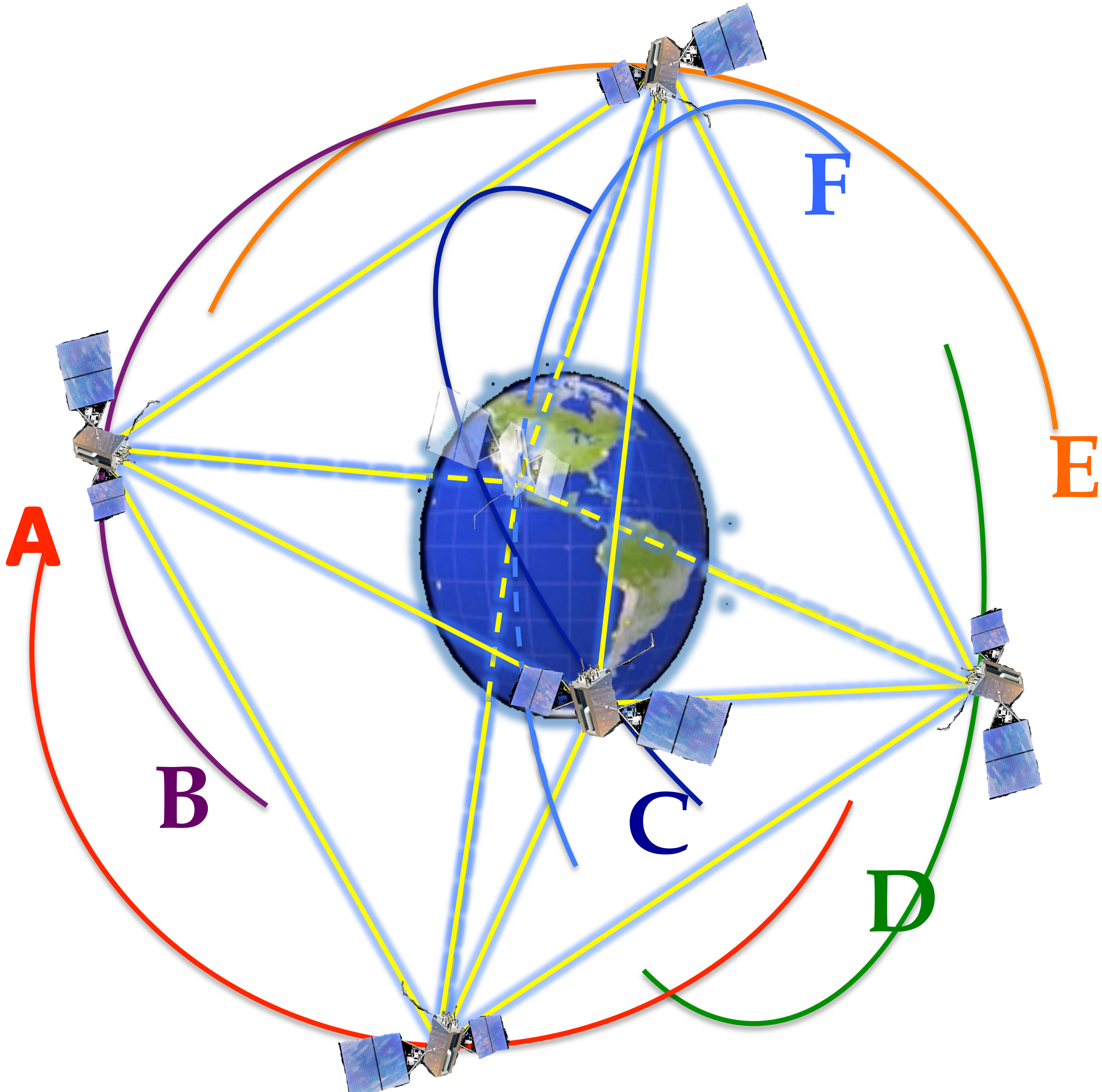
- BeiDou Constellation will have 24 satellites by 2020.
- More passes from ILRS stations is very useful for POD.
  - 5-10 passes each day at the precision of less than 3cm is o.k.
  - Four BeiDou satellites now tracked by ILRS until the end of next year.
- Future plan for SLR system in China:
- Changchun station will set up 1.2 m aperture telescope with the function of laser ranging and satellite imaging in 2016.
- Wuhan station got funding to install a 1-meter telescope for Laser Ranging in the future.
- Shanghai will be developing compact SLR system with the size of 35 cm aperture telescope, it is estimated it will be in use by 2015.
- Future plan for VLBI in China (including San Juan):
- 40-meter antenna VLBI system at San Juan will be established in 2015.
- Shanghai and Urumqi Observatories will develope VLBI 2010.

NGA Requirements

Stephen Malys

- Once a few GPS Block IIIs with LRAs are in orbit, after initial verification of which ILRS stations can successfully track GPS, the following GPS tracking plans will fulfill NGA needs:
  - On day N: Track 4 GPS SVs from 2 planes. 2SVs per plane.
  - On day N+1: Track 4 SVs in 2 different planes (different planes from those picked for Nth day's tracking)
  - On day N+2: Track 4 SVs in remaining 2 planes
  - Repeat process for x [TBD] days.

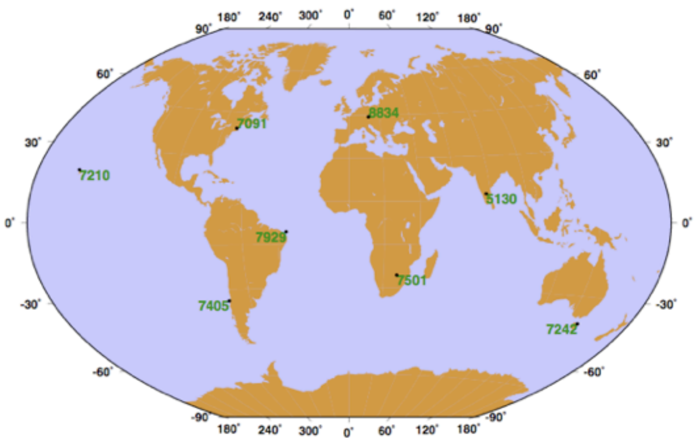
GPS-III CONOPS Concept



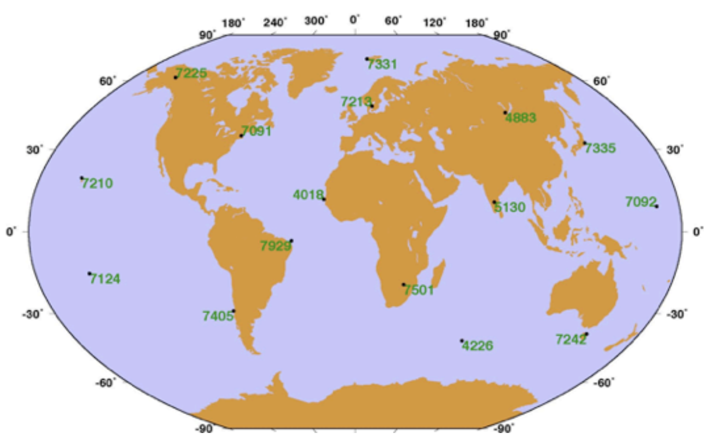
PAST WORK AND PATH FORWARD

SLR Networks Tracking of GNSS Constellations

Next Generation NASA Networks 08 sites



Next Generation NASA Networks 16 sites



- Two SLR networks of NGSLR systems (24/7 operational capability)
- All stations track all s/c of the GPS Constellation as reference
- Errors considered were limited to random walk errors at the stations, similar to those we see at contemporary stations and orbital mis-modeling of non-conservative forces at levels observed on current s/c

Simulated Experiments

- Work with an 8- & 16-site SLR network
  - Same as those used for the SLR & VLBI simulations
- Examine the contribution of SLR tracking to GNSS
  - Can we transfer origin and scale with required accuracy?
- Simulations for 6 GPS s/c
  - Examined the effect of tracking an increasing group of targets on orbit quality:
    - Cases of 1, 2, 3, 4, 5, and 6 s/c tracked (incrementally)
    - Tracking over 1 to 7 days (incrementally by one day)
  - Origin and scale errors for above scheduling
- Examined the effect of such errors on user positioning

GPS Simulation in Summary

- SLR tracking of all GPS s/c from a 16-site network meets or exceeds the accuracy/stability goals set by GGOS.
- A variation with reduced tracking of only one quarter of the GPS s/c is nearly as effective.
- The 16-site network was modified with the removal of key stations, one at a time or in various combinations to simulate outages, etc., and it was observed that:
  - Single site removals affect the origin definition by 20-40% and the scale from 5 to 60% (depending on the site being removed)
  - Removal of pairs of sites results in unacceptable increase in the errors, both in the origin and scale (a 16-site network is the critical size)
- GLONASS simulation capability is now in development and similar experiments can be performed in the near future

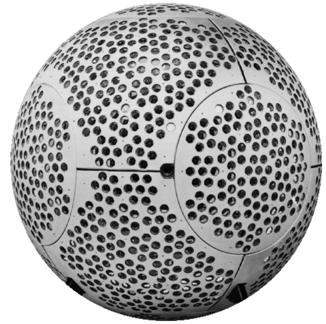
Simulation Scenarios

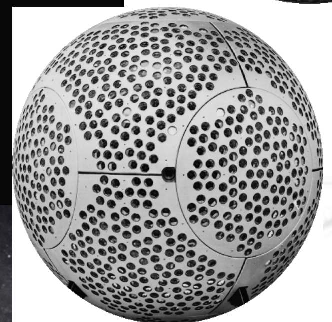
- Different Constellations have different designs and needs for SLR tracking (e.g. number of planes, number of s/c per plane, etc.)
- Simulations will initially generate a full data set of SLR tracking from all possible sites and for all s/c and all times when visible; these can then be used to subsequently sample the data in different ways, e.g.
  - Select a limited number of s/c to be tracked using different criteria:
    - s/c will come from selected orbital planes, e.g. 2, 3, etc. per plane
    - Modify minimum elevation, e.g. 20° vs. 30°, etc.
    - All s/c on a single orbital plane, rotate through all planes after "N" days on each plane
  - Select station sub-networks to track different groups of s/c, mixing orbital planes and sharing a few common sites, etc.

Simulation Scenarios cont.

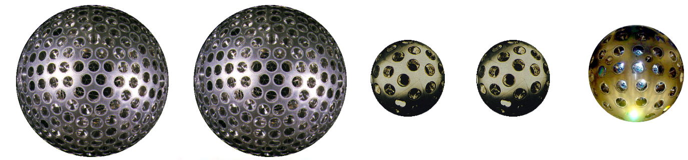
- SLR tracking will likely be limited to "centering" and scaling the orbits that are precisely computed on the basis of microwave data
  - The simulations will require some input from IGS AC products that can be used to 'simulate' these "given" information (i.e. orbits, ancillary parameters, etc.)
- A major effort needs to be devoted in assessing the size of the required sample per day per site and per target:
  - Compare dense tracking to various levels of sub-sampled scenarios, e.g.
    - full coverage of a horizon-to-horizon pass with a NP every 30 min compared to
    - one NP every hour, or,
    - "n" NPs at acquisition, maximum elevation, and prior to loss of contact, where "n": 2, 3, 4, etc.
  - Estimate the amount of time a site spends on a given day in tracking GNSS targets compared to what is spent on everything else
- Since we will examine real data also in order to calibrate the simulations, we will need the laundry list we generated last year for the GNSS to provide us with critical s/c and model information (still incomplete)

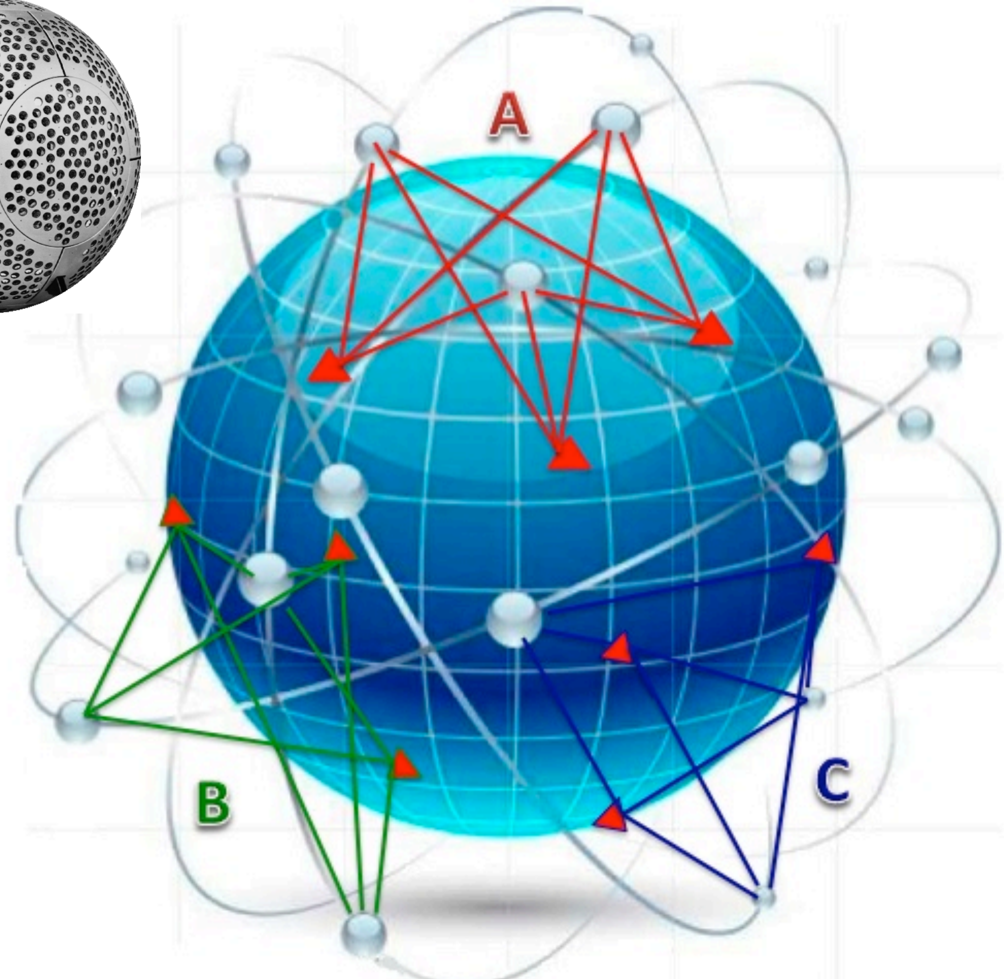
Typical GNSS S/C





SLR Cannonball S/C





Simulations for GPS-III SLR Tracking

Network Origin and Scale Errors				
Simulated Cases	8-Site Network		16-Site Network	
GPS Constellation Size	All s/c (26)	Only 6 s/c	All s/c (26)	Only 6 s/c
Network Scale [ppb]	-0.22±0.5	0.16±0.6	-0.08±0.4	0.19±0.7
Network Origin 3-D [mm]	3.0±2.5	1.6±2.9	1.5±1.3	2.3±2.4